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TESTING OF MODELS OF VVH PARTICLE SOURCES AND PROPAGATION

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For comparisons between theoretical and observed charge spectra of the VVH particles to be meaningful, at least two conditions must be met. First, charge resolution must be adequate to separate important groups of nuclei, and there should be no significant systematic errors in the charge scale developed. Interactions of VVH particles that we have observed give us confidence in the charge scales. Second, there must be adequate rejection of slower particles of smaller Z, which have been observed in several flights. Within these conditions, it has been shown that observed features of the charge spectrum are not accidents of the analysis but reflect real variations in the relative abundances that must be explained by any successful model.

1. Introduction. The extension of cosmic ray observations to nuclei much heavier than the well-established Fe-peak has raised again the problems of the accuracy of individual particle identification and the calibration of the charge scale. Recent measurements, made during the analysis of data accumulated in large-area systems during balloon flights, give us confidence regarding the charge scale while drawing our attention to a hitherto unsuspected source of spurious VVH particles. We describe in this paper the data available to the end of May; updated results will be reported at the meeting and the final data published later.

2. Calibration of the Charge Scale. The methods of measurement and the calibration procedures for the plastic detectors have been described in detail by Blanford et al, (1973). Because relativistic Fe nuclei do not register in even the most sensitive plastic (Daicel cellulose nitrate), the calibration for fast very heavy particles rests on tracks of slow particles, either low energy primary cosmic rays or heavy ions from the HILAC. For emulsions, on the other hand, the prominent Fe-peak is available, but even though the energy loss mechanisms are considered well understood, the identification of the heaviest VVH particles involves ionizations over ten times larger than that of the comparison Fe-nuclei. In our most recent set of plastics

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and emulsions, exposed in a balloon flight from Palestine, Texas, we have observed two VVH particle interactions in which the interlocking identifications of the primary and secondary particles provides an independent test of the charge measurements. In these events, the primary particles were found in routine scanning of detector layers high in the stack. Subsequent attempts at tracing these events through to lower layers revealed, in each case, a bundle of closely spaced and almost parallel tracks. The data are summarised in Table I. Emulsion charge estimates for the heavy particles are derived from photo-densitometer measurements (Fowler et al, 1970; Blanford et al, 1973); for the plastics, etching was carried out under carefully controlled conditions in the Lexan, cellulose triacetate (Bayer TN-CTA) and cellulose acetate butyrate (Bayer BN-CAB) (Blanford et al, 1973).

The lighter secondary particles were identified solely through their tracks in the emulsion, using the conventional procedures. In all the events, exhaustive scanning was carried out to locate the secondary particle tracks and especially those due to singly charged particles. Despite this care, it is possible that a very few secondaries might have been missed, but it is considered unlikely that any spurious secondaries have been wrongly included, for all tracks finally accepted had to satisfy the geometrical reconstruction.

TABLE I
HEAVY PARTICLE INTERACTIONS

Event	Track	Detector		Charge Estimate	Kinetic Energy (GeV/Nucleon)
#1	Primary	A and B emulsions		78	20
		Mean of 4 independent Lexan sheets		75	
	Secondaries	emulsion			
		#1		18	
		#2		15	
		#3		15	
		10 He-nuclei		20	
		2 Li-nuclei		6	
		1 Proton		1	
		Total		75	
#2	Primary	A and B emulsions (no plastics)		78	5
	Secondaries	#1: emulsion	53		
		TN-CTA	50		
		BN-CAB	52		
		Mean		52	
		1 Li-nucleus		3	
		5 He-nuclei		10	
		7 protons		7	
		Total		72	
#3	Primary	emulsion		22	
	Secondaries	emulsion			
		1 Be-nucleus		4	
		2 Li-nucleus		6	
		3 He-nuclei		6	
		7 protons		7	
		Total		23	

From the orientation of the tracks of the secondaries, it was possible to deduce the locations of the actual interactions (none of which actually occurred in an emulsion). The angular divergence of the secondary tracks also permits an energy estimate to be made for each event, and these energies are listed in Table I. These energy values allow us to make better charge estimates than is the case for large samples of random VVH tracks where individual particle energies are not known other than as defined by the geomagnetic cutoff.

Event #3 has been included, for it shows (in the same set of emulsions) the consistency that can be achieved in charge identifying interactions and because its primary was so similar to some of the secondaries in the other events.

From the consistency displayed by these events, it would appear that the charge scales based on our independent calibrations have no serious systematic errors, up to $Z = 78$. Extrapolation to yet higher charges would seem to be reasonable and certainly secure enough for us to separate with confidence Pb_{82} and Bi_{83} from the long-lived r-process nuclei that we have grouped generally together under the designation $Z \geq 86$ (see preceding paper). For very much higher charges, it would seem prudent to extrapolate with caution, for we have observed saturation effects in some of the plastics (Blanford et al, 1973).

3. <u>Rejection of Low Energy Particles</u>. The responses of both the plastics and emulsions to ionizing particles are governed by the rates of loss of energy, and can be very generally represented by relations of the form

$$\left(Z^2/\beta^2\right)\left[A + B\ \ell n\left(\beta^2/1-\beta^2\right) - \beta^2\right].$$

It had been assumed that identification would be easier for particles recorded during balloon flights in regions where the geomagnetic cutoff rigidity was high, for example above 4.5 GV. However, as already reported (Blanford et al, 1972), at a Texas flight location we detected heavily ionizing particles whose kinetic energies were well below the geomagnetic cutoff. We have continued this analysis in another set of plastics and emulsions, also flown over Texas. In this system, a total of close to 2 gm/cm^2 of absorber was distributed between the topmost and lowest detecting layers, and we have found that there were more slow particles and at higher kinetic energies than had been previously recognised.

In the earlier work, we had noted a decrease in the number of particles with kinetic energies above ≈ 150 MeV/nucleon, but with the increased absorber thickness we have now found particles up to 270 MeV/nucleon. Table II shows the spectrum of apparent charges of the particles of this group (i.e., the charges attributed on the basis of the ionization in the top detector layer, assuming that the particles had been fast) and the true charge

spectrum (i.e., the charges as deduced from the changes in ionizqtion observed in successive layers). These 26 particles must be compared to a total of 108 events recorded at altitude; of these, 25 were identified as being due to fast particles with $Z > 40$. The "slow" particle contamination is therefore comparable to the VVH particle flux, and, as can be seen from Table II, can be serious if unrecognised.

Table II
Distribution of Charges

Charge Group	8-10	11-20	21-30	31-35	36-40	41-45
Apparent Charges	-	-	4	11	8	3
True Charges	5	6	15	-	-	-

In order for an Fe Nucleus to ionize as heavily as a fast nucleus of $Z \sim 50$, it must be so slow that its range will be less than 1 gm/cm^2; correspondingly, detector stacks of at least this thickness can provide a clean sample of particles with $Z \gtrsim 50$, but the problem of contamination becomes more severe as one approaches $Z = 30$ when greater absorber thicknesses (or a velocity indicator such as Cerenkov counter) are needed.

4. The Charge Spectrum Observed for VVH Particles. In the preceding paper, the accuracy of the charge determinations was given as $Z = {}^{+3}_{-6}\%$ these limits are largely set by the uncertainty in the particles' kinetic energies. With the arrival zenith angle known, there is still uncertainty in the azimuthal angle and, as a result, in the geomagnetic cutoff. Even for particles that are too fast to exhibit detectable energy losses in the 1 or 2 gm/cm^2 of absorber, there is a residual uncertainty in velocity and thus an uncertainty in the assigned charge. Caution must therefore be exercised in not overinterpreting the data, and we prefer to present our results in charge groups that are 5 charge units wide. With the slow particles rejected, and with the interactions giving support to the charge scale, we may consider that the general features of the charge spectrum--such as the high or low abundance of different charge groups--can be considered significant. More detailed features such as prominent peaks of individual nuclides, must await improved techniques, better velocity information (in the case of fast particles) and larger numbers of events.

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